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APPROPRIATE MAWP STATIC GAS LOAD FOR LAUNCHING GRENADES FROM THE M-16, A-1 RIFLE

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March 12, 1986

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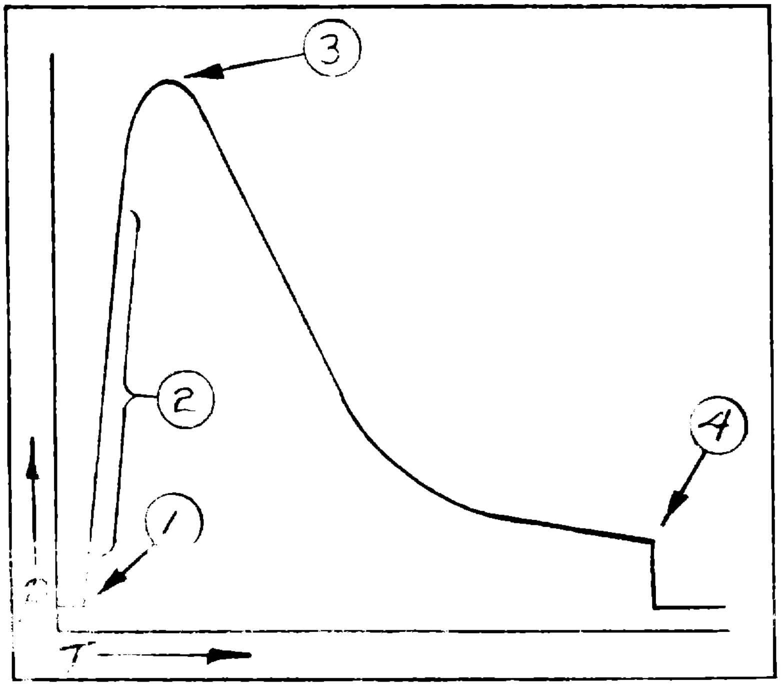
ABSTRACT

Launching small grenades from the muzzle of a service rifle constitutes an abnormal use of standard propellants used in loading ammunition. An analysis of system strength capabilities, types and characteristics of mechanical loading, appropriate safety factors and the energy producing characteristics of various propellant types is needed to better understand how this might be done safely. Then specific propellant loading recommendations are made based on these findings.

On November 1, 1985 I was asked to attend a meeting of the group working on the Boom Launched Rifle Grenade for the purpose of addressing the problem of an appropriate propellant load. I explained the difference between the time/pressure relationship for a modern smokeless powder rifle launching a typical projectile (i.e., the 5.56 mm M-193 round in the M-16) and the time/pressure relationship for the same rifle used to launch a grenade. Essentially, when a rifle is used to launch a typical projectile, the projectile is held in place directly over the powder charge at the moment of firing, and the propellant gases must overcome both the projectile's mass and the engraving forces necessary to engage the rifling, plus friction. This causes a sharp initial rise in breech pressure. As the projectile moves down the barrel, the effective chamber volume increases at a higher rate than the ability of the burning propellant to supply additional gas, so the pressure drops until the projectile reaches the muzzle at which time the pressure falls to zero very quickly.[1] This is shown by the idealized curve in Figure 1.

FIGURE 1



(1) Moment of Firing

(2) Projectile Starts to Move

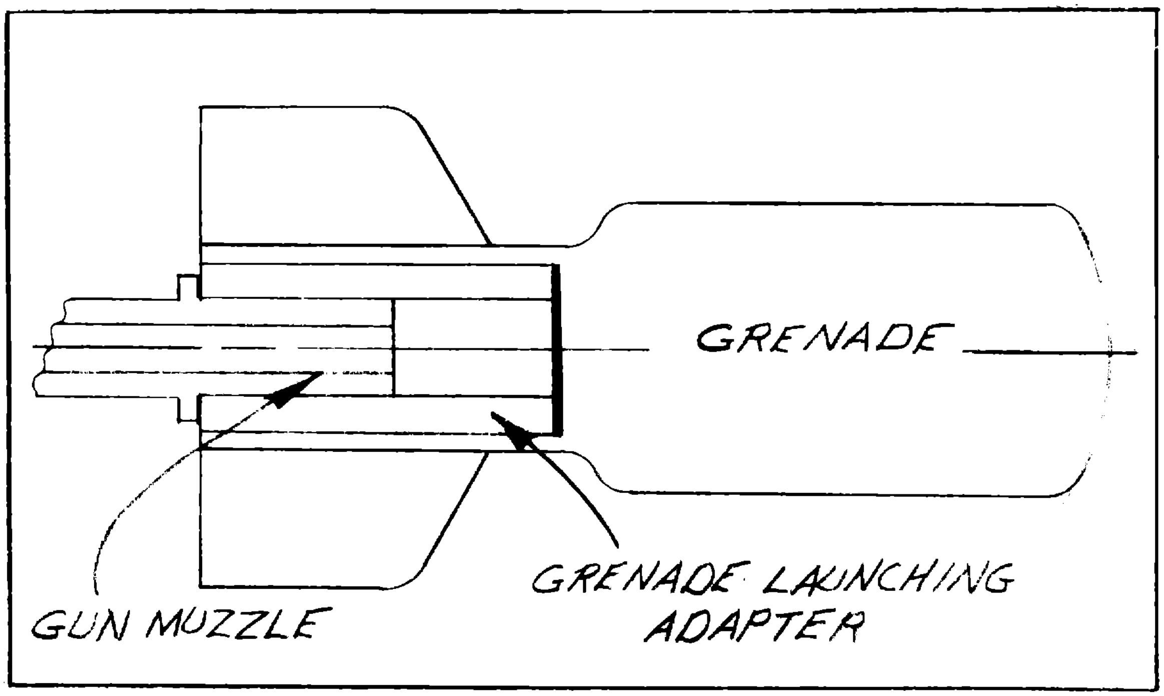
(3) Peak Breech Pressure

(4) Projectile Leaves Muzzle

The projectile/powder ratio of a normal rifle round is also relatively low (about 2/1) which contributes to the curve taking this form. In an event history such as this, it is normal for peak breech pressures to reach 55-65 K.S.I. which is near the failure point of the materials normally used in small arms construction.[2] The reason they don't fail is that peak breech pressure exists for a very short time; usually $\leqq$ 300 μ s.[1] If the duration of that peak breech pressure were prolonged, weather by plugging the barrel or by substituting a much heavier projectile for the normal one, two things would happen. First, the peak breech pressure would continue to rise even higher, perhaps to exceed 300 K.S.I, then the system would fail catastrophically.[3]

When a grenade is launched, both of the previously mentioned criteria are met. The barrel is plugged, and a much heavier projectile is substituted; in this case, up to 300 times heavier (See Figure 2).

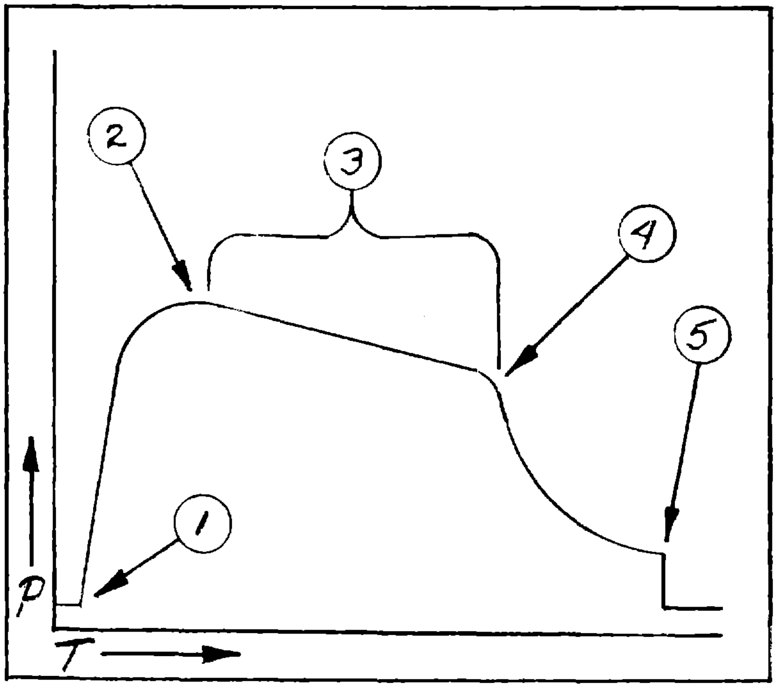
FIGURE 2



Therefore, using a normal powder charge to launch a grenade would not be desirable.

Ideally, the best way to launch a grenade would be to introduce a gas charge at a pressure that the gun could handle safely as a static load, through a fast acting valve, much the same as is done with a pellet gun. But this is not possible with a powder actuated gun, so the next best method must be employed. That is to use a powder charge small enough to produce only enough gas to create a safe static pressure. This is because the mass of a grenade is so great that it will not begin to move until long after all the powder has burned and the gas pressure has equalized throughout the chamber and barrel, effectively creating a static pressure. This is best illustrated by the time/pressure relationship shown on the idealized curve in Figure 3.

FIGURE 3



(1) Moment of Firing

(2) Peak Pressure Reached

(3) "Static" Pressure

(4) Grenade Starts to Move

(5) Grenade Leaves Muzzle

It also might be mentioned that this effect is best created by a "fast" powder such as a pistol powder. The slower powders normally used as propellant for rifle rounds require good confinement for proper ignition,[4] a condition that does not exist with a grenade launching cartridge.

DETERMINATION OF MAWP STATIC GAS LOAD FOR THE M-16, A-1 RIFLE

The first step in determining an appropriate maximum load for grenade launching is to determine the maximum allowable static gas load for the gun system. To do this, a number of assumptions are made:

1. That the gun system itself is of primary concern in determining gas load; not the cartridge case. (We don't care if we damage the cartridge case.)

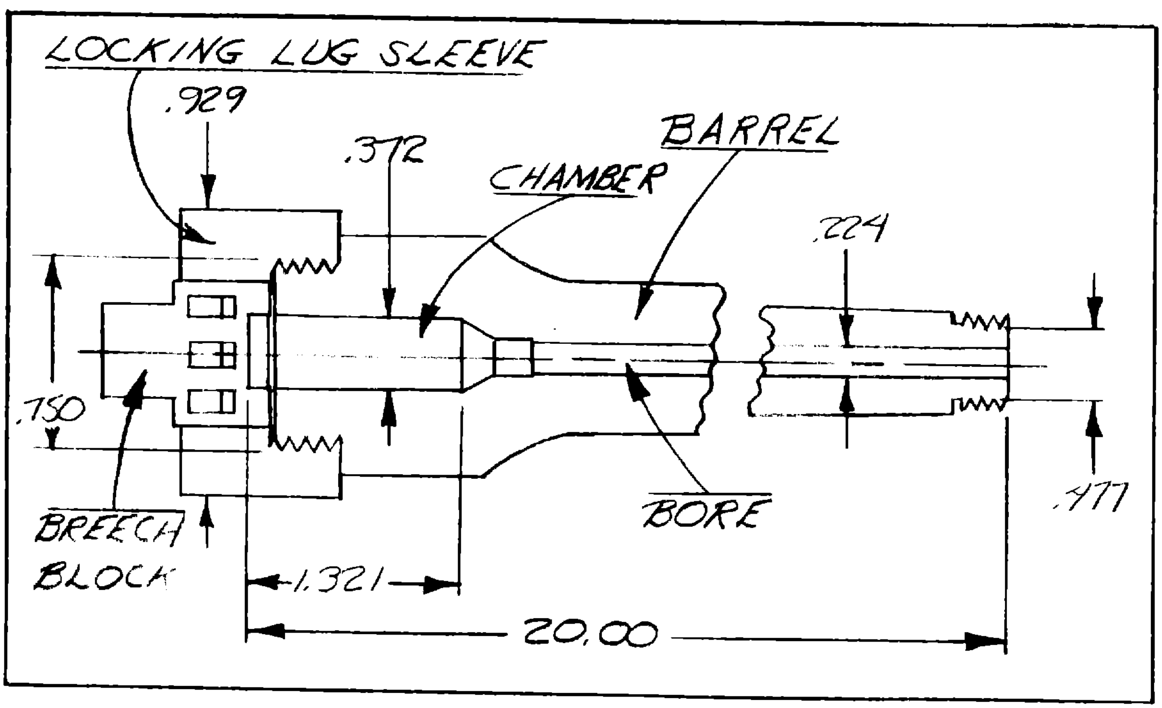
2. That the system is a chambered tube, closed on one end by the breech block, on the other end by the bluff tail end of the grenade and is gas tight.

3. That the gas port has been closed off to allow neither the escape of gas nor the operation of the mechanism.

4. That the cartridge case does not exist. This was done in order to be conservative and for simplicity. In actuality, the cartridge case contributes substantially to the overall integrity of the system.

The system is illustrated in Figure 4.

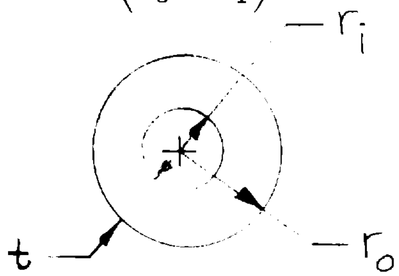
FIGURE 4



Using Roark's equation for hoop stress (in this case the weakest mode for the system--more so than axial stress or radial stress) and treating the barrel as a "thick" cylinder ($\frac{t}{r_i} > 0.1$).[5]

$$S = P\left(\frac{r_o^2 + r_i^2}{r_o^2 - r_i^2}\right) \text{ or}$$

$$P = \frac{S}{\left(\frac{r_o^2 + r_i^2}{r_o^2 - r_i^2}\right)}$$



Where: S = Ultimate Tensile Strength of the Material Used

P = Pressure at Failure

t = Wall Thickness

r_o = Outside Radius

r_i = Inside Radius

Data for S.A.E. 4140 steel at R_c-28 was selected[2] because this is a commonly used gun steel for barrels and other critical parts, although Colt may now be using 8640 nickel steel with a U.T.S. of 126 K.S.I. The U.T.S. of 4140 steel at R_c-28 is 100 K.S.I. It is normal for barrel steels to be at this relatively soft temper to ease machining, although parts such as the breech block and breech block ring carry a higher temper, usually about R_c-36-42.

This calculation was performed for two points along the barrel deemed thinnest; the minor diameter of the threaded portion of the muzzle and the minor diameter of the threaded portion of the breech end just over the position of the cartridge case head. In all cases:

S = 100,000 P.S.I.

In the first case r_o = .2385"

and r_i = .1120"

$\therefore$ For the First Case

$$P = \frac{S}{\left(\frac{r_o^2 + r_i^2}{r_o^2 - r_i^2}\right)} = \frac{100,000}{\left(\frac{.2385^2 + .112^2}{.2385^2 - .112^2}\right)} = \underline{\underline{63,864 \text{ P.S.I.}}}$$

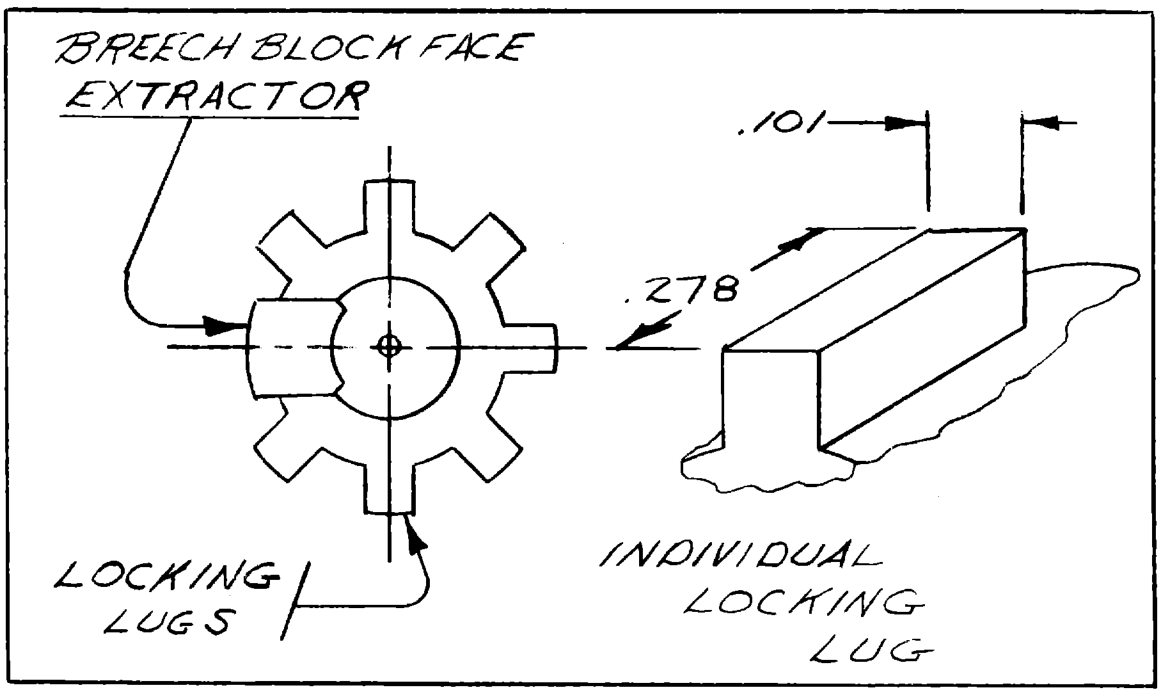
And for the Second Case

$r_o = .375"$
and $r_i = .186"$

$$\therefore P = \frac{100,000}{\left(\frac{.375^2 + .186^2}{.375^2 - .186^2}\right)} = \underline{\underline{60,512 \text{ P.S.I.}}}$$

In the case of the breech block, all of the load is aft which means the failure mode would be by shear. To calculate the pressure needed in the chamber to induce locking lug failure, first the total root area of the locking lugs was calculated. There are seven locking lugs equally spaced around the breech block at 45° intervals with one space left open to allow for an extractor. See Figure 5.

FIGURE 5



Therefore, total locking lug root area is:

$$A = .278 \times .101 \times 7 = .1965 \text{ sq. in.}$$

The shear strength of 4140 steel at R_c-28 is about 50% of its ultimate tensile strength or 50 K.S.I., so the total static load at failure of the lugs should be .1965 x 50,000 = 9825 lbs.

The cartridge base area pushing on the locking lugs, based on a cartridge base diameter of .372" is:

$$A = \pi \times .186^2 = .1087 \text{ sq. in.},$$

so the static pressure to shear the locking lugs is:

$$P = \frac{9825}{.1087} = \underline{\underline{90386}} \text{ P.S.I.}$$

The same calculation was not run for the locking lug sleeve because the total locking lug root area for it is greater.

CONCLUSION

Since the lowest static pressure calculated for failure is 60,512 P.S.I., by allowing a safety factor of 3 to 1, then the maximum peak pressure (which is also the maximum allowable working pressure in this case) for grenade launching would be = 20,000 P.S.I. These estimates are intended to be conservative. The materials used in the breech block and locking lug sleeve probably have a U.T.S. of at least 150 K.S.I. Also, the locking lug sleeve would contribute substantially to the ultimate strength of the barrel in the cartridge case head area in addition to the previously mentioned contribution of the cartridge case.

RECOMMENDATIONS

Since we now have determined that we wish a static pressure in this system no greater than 20,000 P.S.I., we must determine the powder charge best able to achieve this. We can find this with the general gas equation:[6]

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

for initial and final conditions. To make this equation useful we must first know how much gas each gram of powder will produce at S.T.P. The published constant for most single and double based (nitrocellulose or nitrocellulose/nitroglycerin) smokeless propellants is .04 - .05 moles of gas/gram of propellant.[7] Using the constant 1 gram mole of gas = 22,414 liters at S.T.P. each gram of powder = (22.414)(.05) = 1.1207 liters of gas at S.T.P.

We can now use the above general gas equation. The unknown is the initial volume of the gas, V_1.

Given are:

P_1 = 14.7 P.S.I.A. ≈ P = 1 (amagat)[8]

V_1 = ?

T_1 = 25°C + 273°K = 298°K (absolute Standard Temperature)

P_2 = 20,000 P.S.I.A. ≈ P = 525 (amagat for N_2)

V_2 = .0144 ℓ (volume of barrel and chamber)

T_2 = 3800°K

So:

$$\frac{(1P)(V_1)}{298^\circ K} = \frac{(525P)(.0144\ell)}{3800^\circ K}$$

$$V_1 = \frac{(525)(.0144\ell)(298)}{3800} = .5929\ell$$

$$\therefore \frac{.5929 \ \ell \text{ at S.T.P.}}{1.1207 \ \ell \text{ at S.T.P.}} = .529 \text{ gm of propellant}$$

This figure is quite conservative because a number of assumptions are made to arrive at it.

1. The Figure of 3800°K for T_2 is based on the core flame temperature of double based propellant containing a high percentage of nitroglycerin.[9] This temperature is very short in duration in small arms and is lower near the chamber and barrel walls. The temperature may also be lowered by as much as 800°-1000°K by using single based propellants.

2. Because temperatures within the barrel and chamber will begin to fall almost immediately after firing a true static pressure will not be produced -- the pressure will lower as the temperature lowers. There will also be substantial lowering of pressure/temperature due to adiabatic expansion.

3. The above figure assumes that the propellant is 100% efficient; that all of it turns into gas.

4. The amagat numbers are for N_2 for convenience -- the gases produced are much more complex compounds of nitrogen and carbon plus water vapor and solids -- the amagat numbers could be expected to be somewhat lower.[10]

Even though the figure of .529 gm of propellant is conservative, I would recommend a starting load of .50 gm, especially considering the relatively "fast" propellants I am recommending below.

The choice of propellants is dictated by two factors. The primary factor is the ability of the primer ignition system to properly ignite them. "Slower", more progressive propellants normally used to launch ordinary rifle projectiles require substantial initial confinement and high peak pressure to fully ignite and burn properly.[11] Because there will be little initial confinement and relatively low peak pressure in this launch system, these propellants would be inappropriate. Much better would be the relatively "fast" propellants normally reserved for use in loading shotgun and pistol ammunition.

The second factor is the availability of uniform, commercially available canister lots of propellant. Because these are made to a very uniform and repeatable standard, they are most appropriate for laboratory testing. Specifically, I recommend propellants be selected from the following list of commercially available canister lots. The list is given from the "slowest" to the "fastest".

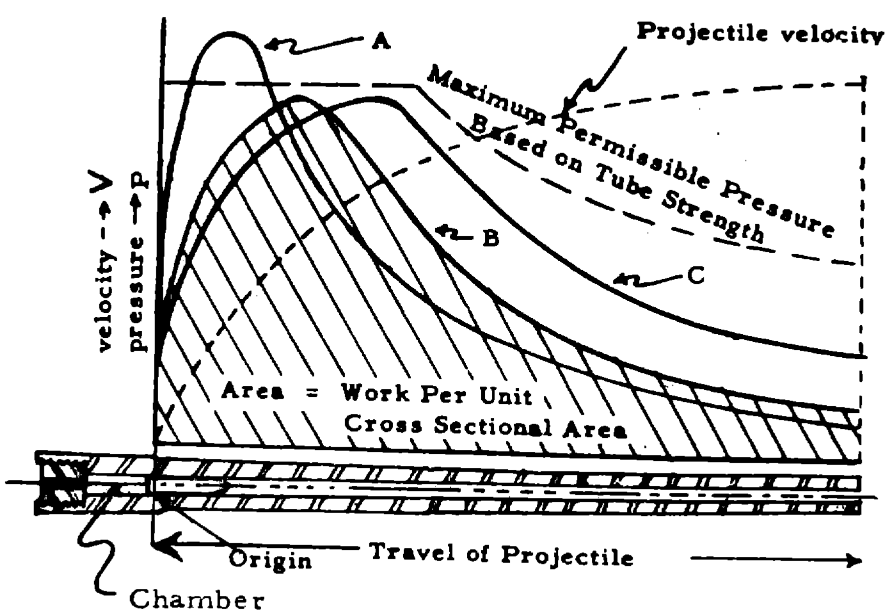
(Bullseye powder is listed here largely for comparison purposes. Its use is normally limited to very light charges in pistols and revolvers for low recoil-noise-velocity target ammunition. It is the least stable of all the propellants listed. It is the only commercially available canister lot propellant known to truly detonate, rather than deflagrate, by low level shock wave and flame front initiation. This propellant is potentially destructive in this application and should not be considered except as a "last resort".)

Propellant Designation	Manufacturer	(See Ref. 12)
2400 *	Hercules	
630 *	Olin	
R-123	Norma	
AL8	Alcan	
571 Ball Powder *	Olin	
Blue Dot *	Hercules	
Herco *	Hercules	
HS7	Hodgdon	
540 Ball Powder *	Olin	
AL7	Alcan	
473AA *	Olin	
AL5	Alcan	
HS6 *	Hodgdon	
SR7625	Dupont	
Unique *	Hercules	
HS5	Hodgdon	
SR4756	Dupont	
Green Dot *	Hercules	
Trap 100	Hodgdon	
452 *	Olin	
Hi-Skor 700X *	Dupont	
Red Dot *	Hercules	
HP38	Hodgdon	
R-1	Norma	
231 *	Olin	
Bullseye *	Hercules	

* Indicates double base propellants.

More specifically, I recommend a starting load of .50 gm Hercules 2400. Work up in charge at a rate of no more than .2 gm at a time and check for pressure signs on both the cartridge case and the breech bolt locking lugs after every shot. If there are signs of substantial amounts of unburned propellant after a shot I recommend moving on to a "faster" burning propellant and starting back at .50 gm charge weight. If your barrel is instrumented with strain gages and you know the peak pressure and configuration of the time/pressure curve of each shot, you may be able to "push" the 20,000 P.S.I. limit I have set here. Depending on the duration of the peak pressure, you may be able to reach a substantial percentage of normal peak breech pressure without harming the gun, if at no point on the time/pressure curve you allow it to exceed the maximum permissible pressure based on tube (barrel) strength. See Figure 6.[13]

FIGURE 6



I would be happy to assist you in determining this, or in any other matter regarding this project that may arise in the future.

I wish to express my gratitute to D. B. Frischknecht, C. A. Honodel, and B. L. Hord for their assistance and expertise.

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6. Ibid, pp. 2-5.

7. Conversation with C. Honodel.

8. Ibid, Ref. 5, above; pp. 2-7.

9. Ibid, Ref. 4, above; pp. 1-9.7, 1-9.8.

10. Ibid, p. 1-9.13.

11. Ibid, pp. 1-6, 1-7.

12. Speer Reloading Manual Number 10, (Research staff of Speer/Omark Industries, Inc., Lewiston, Idaho), pp. 42-43.

13. Ibid, Ref. 4, above; pp. 1-5, 1-6.